Low-scale sessaw mechanisms and how to test them

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- the various seesaw mechanisms
- constraints on heavy sterile neutrinos
- heavy Majorana neutrino production at colliders
- scalar and fermionic electroweak triplets

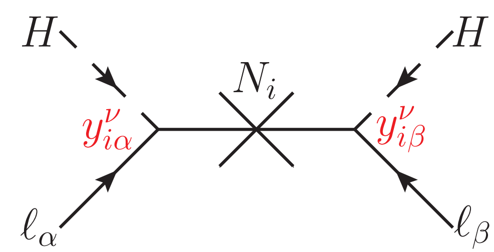
GDR Neutrino
Saclay, 5 November 2015

The seesaw mechanism

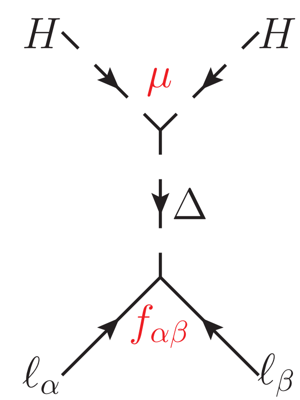
[Benoît Schmauch]

Generalization: heavy fields that couple both to lepton ($\not{L}$) and Higgs doublets $\rightarrow$ Majorana neutrinos

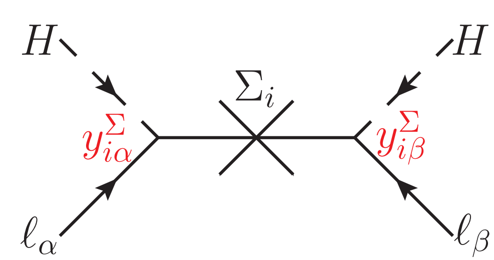
1. RH neutrinos N_i (Type I seesaw)
   [Minkowski - Mohapatra & al - Gell-Mann & al - Yanagida]



2. Scalar $SU(2)$ triplet Δ (Type II seesaw)
   [Schechter & al - Lazarides & al - Mohapatra & al - Wetterich]



3. Vector-like fermion $SU(2)$ triplets Σ_i (Type III seesaw) [Foot & al]



[Deppisch, Dev, Pilaftsis, arXiV:1502.06541]

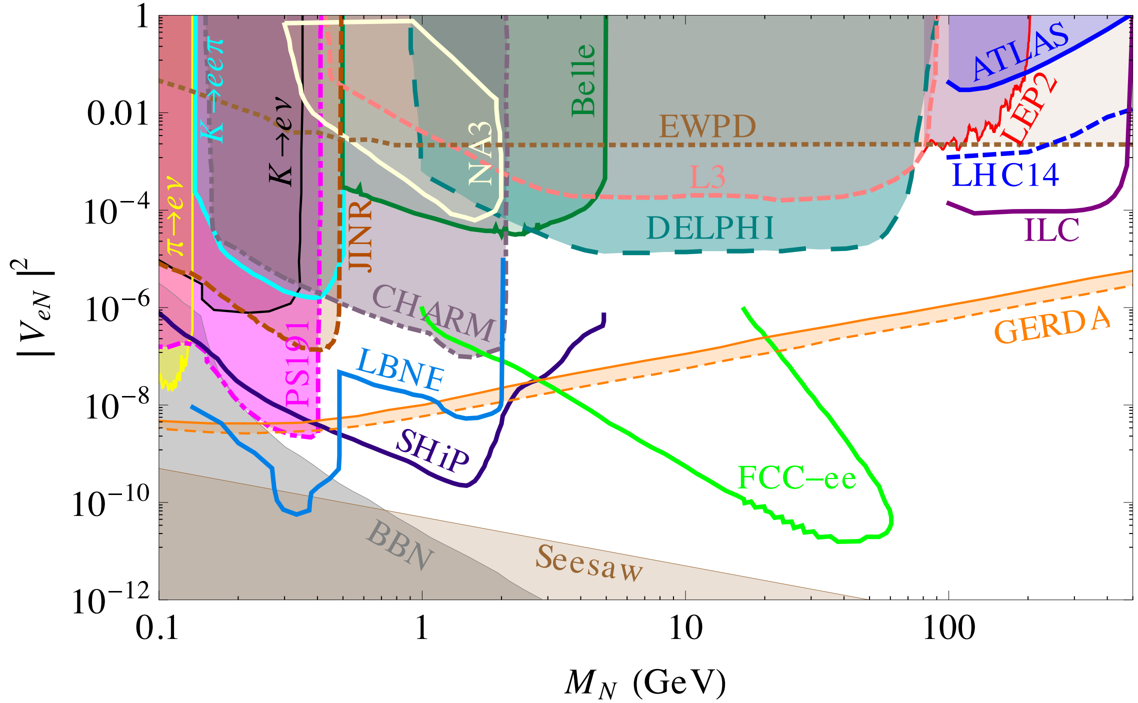


Figure 3. Limits on the mixing between the electron neutrino and a single heavy neutrino in the mass range 100 MeV - 500 GeV. For details, see text.

[arXiV:1502.06541]

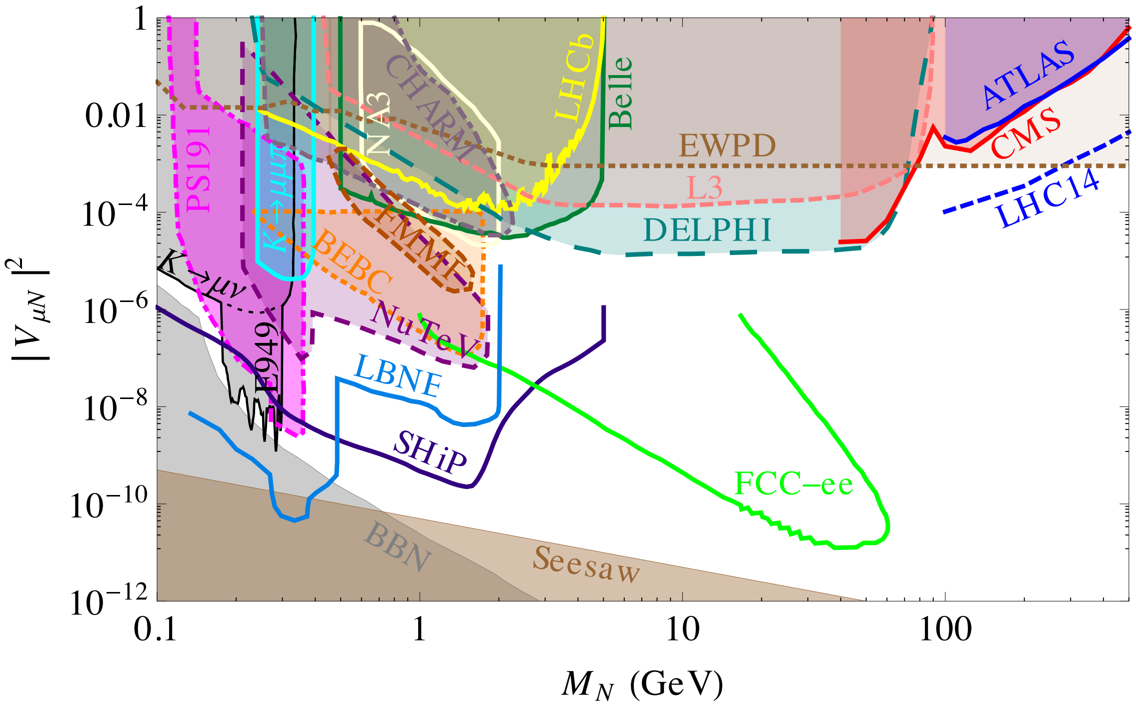


Figure 4. Limits on the mixing between the muon neutrino and a single heavy neutrino in the mass range 100 MeV - 500 GeV. For details, see text.

[arXiV:1502.06541]

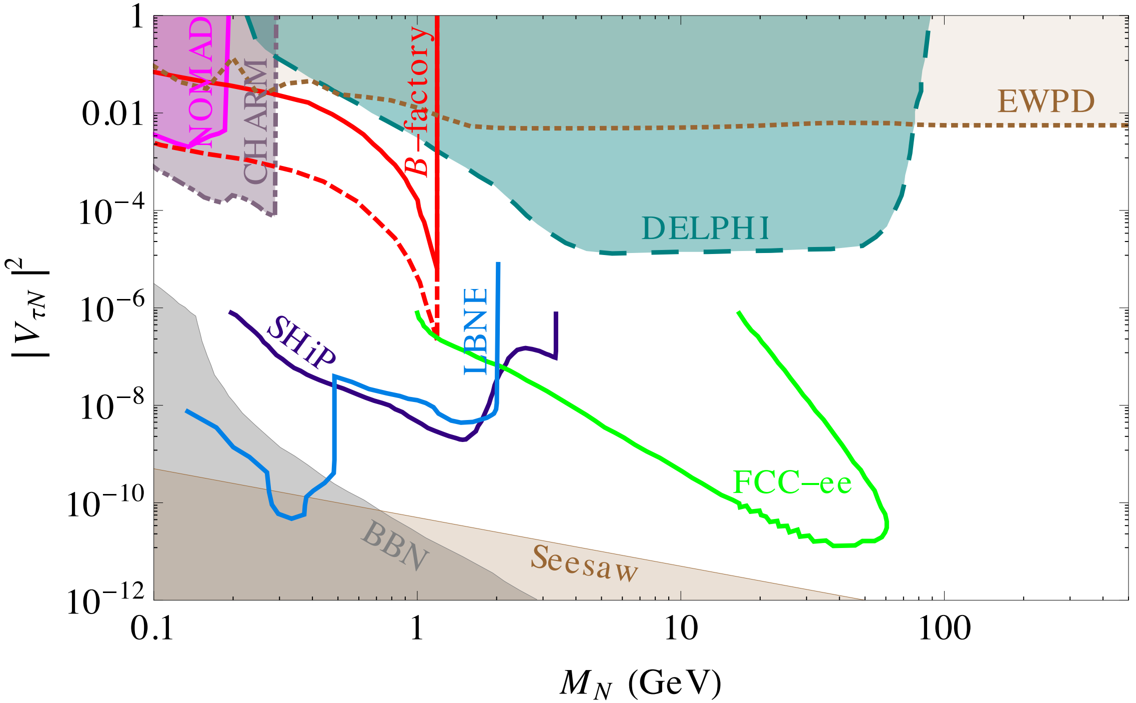


Figure 5. Limits on the mixing between the tau neutrino and a single heavy neutrino in the mass range 100 MeV - 500 GeV. For details, see text.

[A. Blondel et al., arXiv:1411.5230]

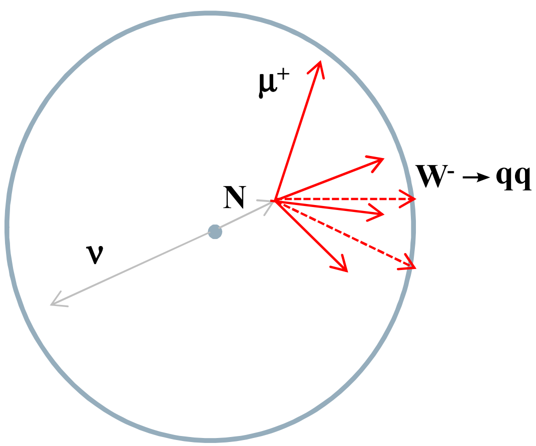


Figure 7: Sketch of the topology of a $Z \to \nu N$ decay, with N subsequently decaying into $\mu^+ W^-$.

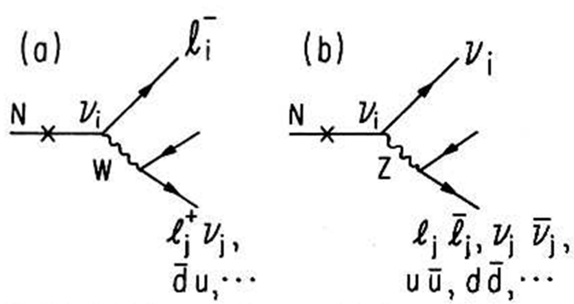
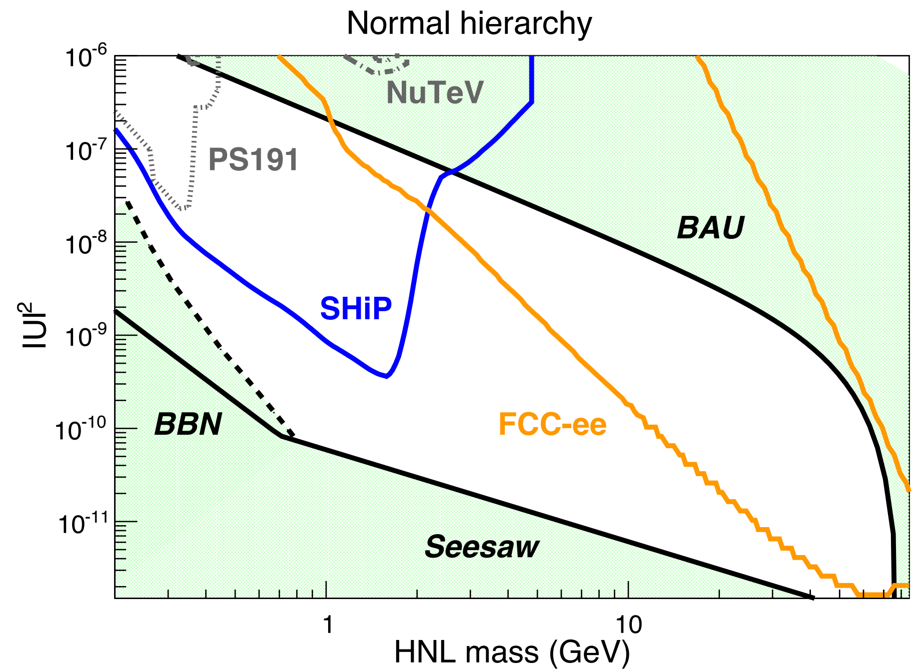
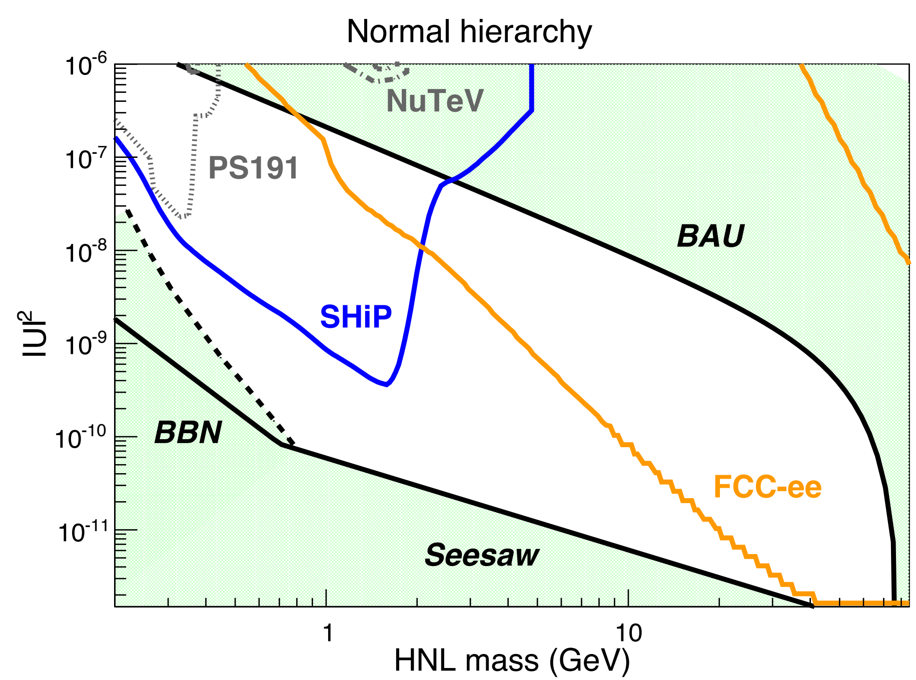


Figure 4: Decay modes of heavy neutrinos through mixing with light neutrinos: the charged current decay $N \to \ell\nu$ (a), the neutral current decay $N \to \nu + \gamma/Z$.



(b) Decay length 10-100 cm, 10^{13} Z^0



(c) Decay length 0.01-500 cm, 10^{13} Z^0

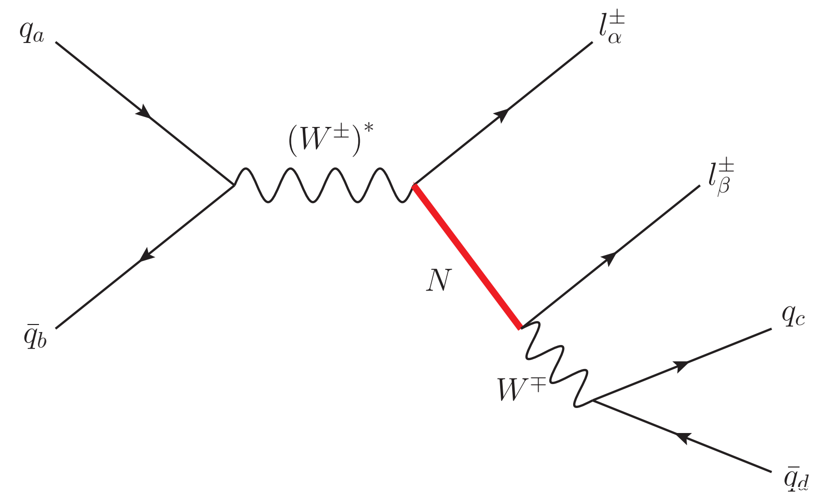


Figure 1: The tree-level diagram for the production of a heavy Majorana neutrino (N) in the mTISM model. Lepton flavour is denoted by α and β. Lepton flavour is assumed to be conserved, such that $\alpha = \beta$. The W boson produced from the N decay is on-shell and, in this case, decays hadronically.

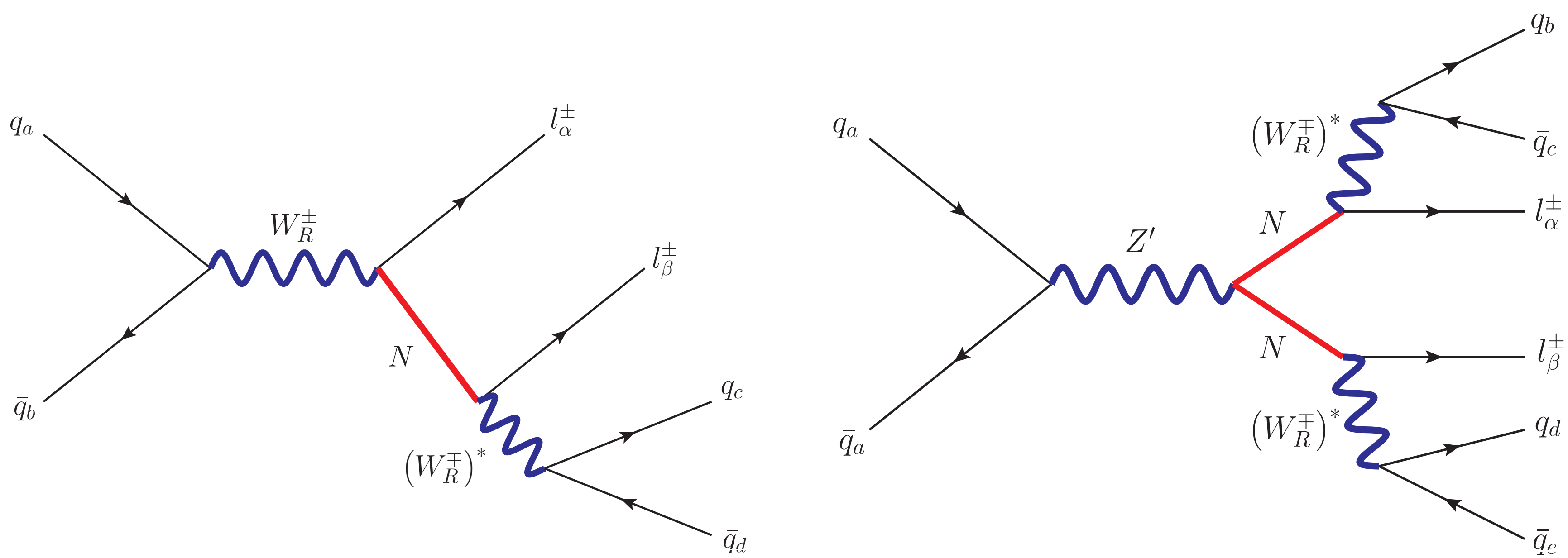
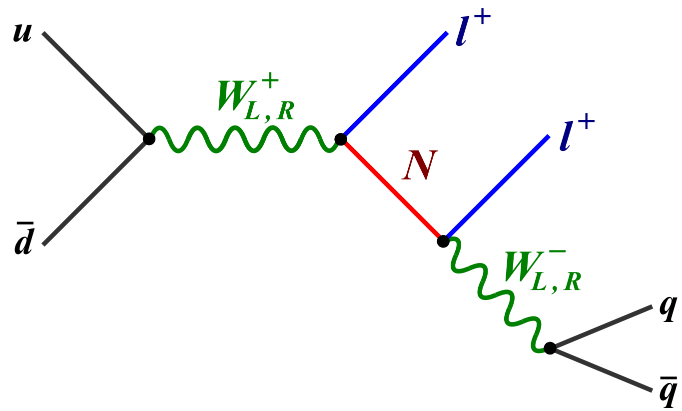


Figure 2: The tree-level diagrams for the production of a heavy Majorana neutrino (N) in the LRSM model, in which heavy gauge bosons W_{R} and Z' are also incorporated. Lepton flavour is denoted by α and β. Lepton flavour is assumed to be conserved, such that $\alpha = \beta$. The W_{R} boson produced from the N decay is off-shell and, in this case, decays hadronically.

[arXiV:1502.06541]



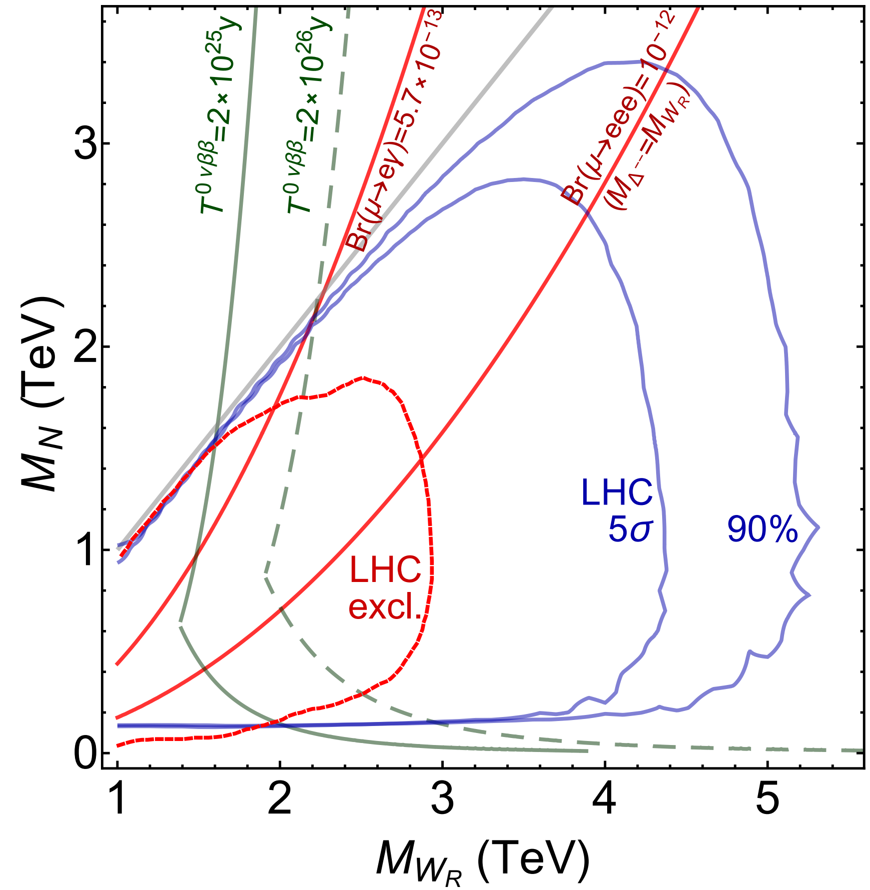


Figure 10. *Left:* Feynman diagrams contributing to the 'smoking gun' collider signal of LNV ($\ell^\pm\ell^\pm jj$) in the LRSM through the production via SM $W_{(L)}$ and heavy W_R, giving rise to 4 different contributions: RR, RL, LL, LR. *Right:* Comparison of LNV event rates via the RR diagram at the LHC and in $0\nu\beta\beta$ experiments [307]. The solid blue contours give the signal significance of 5σ and 90% at the LHC with 14 TeV and $\mathcal{L} = 300$ fb^{-1}. The area denoted 'LHC excl.' is excluded by current LHC searches in the electron channel [305]. The green contours show the sensitivity of current and future $0\nu\beta\beta$ experiments, assuming dominant doubly-charged Higgs or heavy neutrino exchange and the red contours show the sensitivity of LFV processes as denoted.

Neutrinoless Double Beta Decay in the LRSM

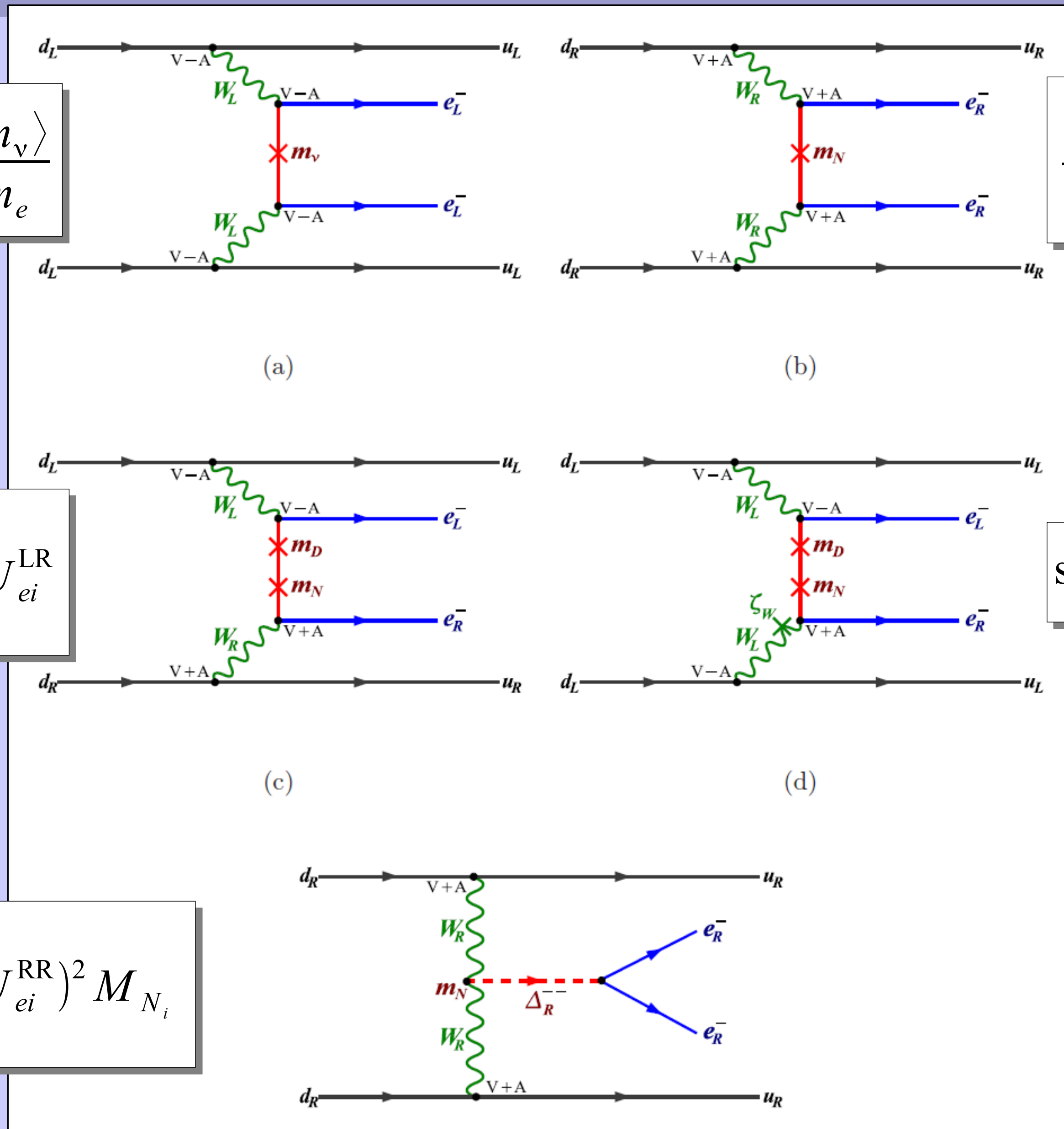
$$\sum_i (U_{ei}^{\mathrm{LL}})^2 \frac{m_{\nu_i}}{m_e} = \frac{\langle m_\nu \rangle}{m_e}$$

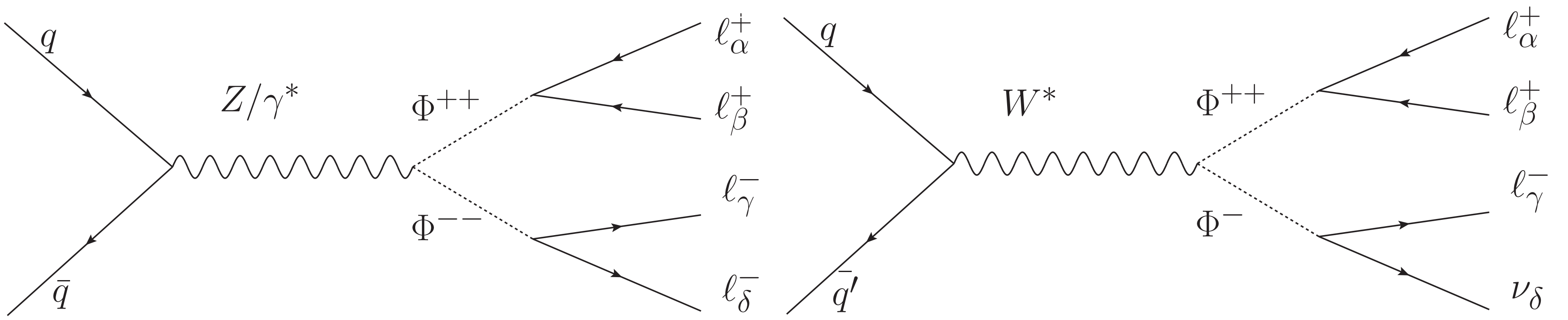
$$\frac{M_{W_L}^4}{M_{W_R}^4} \sum_i \frac{(U_{ei}^{\mathrm{RR}})^2}{M_{N_i}}$$

$$\left(\frac{M_{W_L}}{M_{W_R}}\right)^2 \sum_i U_{ei}^{\mathrm{LL}} U_{ei}^{\mathrm{LR}}$$

$$\sin^2\zeta \sum_i U_{ei}^{\mathrm{LL}} U_{ei}^{\mathrm{LR}}$$

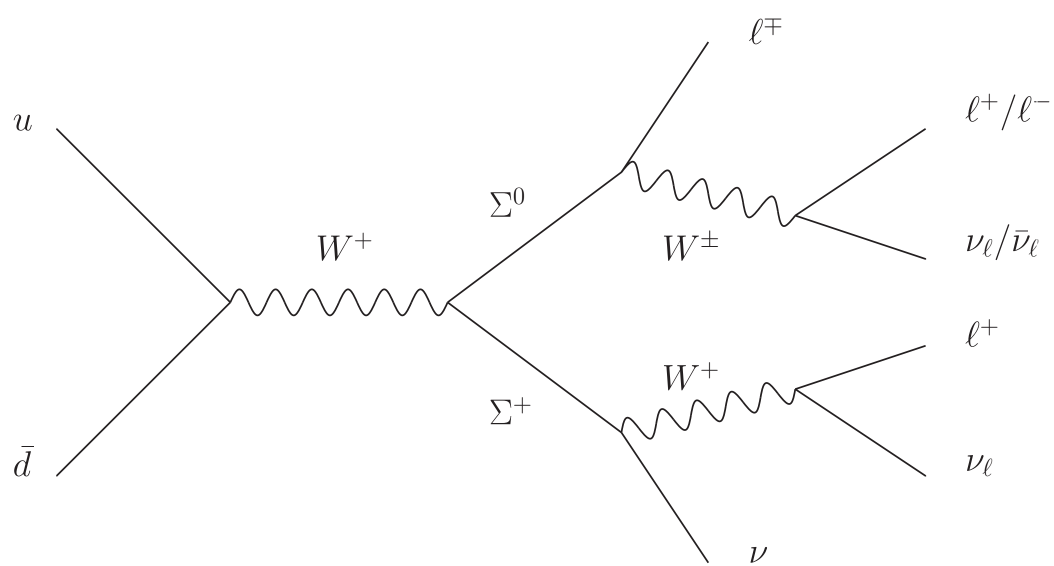
$$\frac{M_{W_L}^4}{M_{W_R}^4} \frac{m_p}{M_{\Delta_R^{--}}^2} \sum_i (U_{ei}^{\mathrm{RR}})^2 M_{N_i}$$





CMS, arXiv:1207.2666

Figure 1: Feynman diagrams for pair and associated production of Φ^{++}.



CMS, arXiv:1210.1797

Figure 1: Feynman diagram for the dominant contribution to three-charged-leptons final states in pair production of Σ in the type III seesaw models. The production cross section for the charged-conjugate intermediary W^- is expected to be about a factor of two smaller.